

Appendix A

Emission Factor Derivations

The following physical constants and standard conditions were utilized to derive the criteria-pollutant emission factors used to calculate criteria pollutant and toxic air contaminant emissions.

standard temperature ^a :	70°F
standard pressure ^a :	14.7 psia
molar volume:	385.3 dscf/lbmol
ambient oxygen concentration:	20.95%
dry flue gas factor ^b :	8535 dscf/MM Btu
natural gas higher heating value:	1030 Btu/dscf

^aBAAQMD standard conditions per Regulation 1, Section 228.

^bF-factor is based upon the assumption of complete stoichiometric combustion of natural gas. In effect, it is assumed that all excess air present before combustion is emitted in the exhaust gas stream. Value shown reflects the typical composition and heat content of utility-grade natural gas in San Francisco bay area.

Table A-1 summarizes the regulated air pollutant emission factors that were used to calculate mass emission rates for each source. All units are pounds per million Btu of natural gas fired based upon the high heating value (HHV). All emission factors are after abatement by applicable control equipment.

Table A-1
Controlled Regulated Air Pollutant Emission Factors for
Gas Turbines and HRSGs

Pollutant	Source			
	Gas Turbine		Gas Turbine & HRSG Combined	
	lb/MM Btu	lb/hr	lb/MM Btu	lb/hr
Nitrogen Oxides (as NO ₂)	0.00897 ^a	16.8	0.00897 ^a	20.0
Carbon Monoxide	0.013 ^b	24.5	0.013 ^b	29.2
Precursor Organic Compounds	0.00255	4.77	0.00250	5.57
Particulate Matter (PM ₁₀)	0.0059	11	0.00584	13
Sulfur Dioxide	0.00227	6.18	0.00227	5.19

^abased upon the permit condition emission limit of 2.5 ppmvd NO_x @ 15% O₂ that reflects the use of dry low-NO_x combustors at the CTG, low-NO_x burners at the HRSG, and abatement by the proposed A-11 and A-13 Selective Catalytic Reduction Systems with ammonia injection

^bbased upon the permit condition emission limit of 10 ppmvd CO @ 15% O₂

REGULATED AIR POLLUTANTS

NITROGEN OXIDE EMISSION FACTORS

Combustion Gas Turbine and Heat Recovery Steam Generator Combined

The combined NO_x emissions from the CTG and HRSG will be limited to 2.5 ppmv, dry @ 15% O₂. This emission limit will also apply when the HRSG duct burners are in operation. This concentration is converted to a mass emission factor as follows:

$$(2.5 \text{ ppmvd})(20.95 - 0)/(20.95 - 15) = 8.8 \text{ ppmv NO}_x, \text{ dry @ 0\% O}_2$$

$$(8.8/10^6)(1 \text{ lbmol}/385.3 \text{ dscf})(46.01 \text{ lb NO}_2/\text{lbmol})(8535 \text{ dscf/MM Btu})$$

$$= \mathbf{0.00897 \text{ lb NO}_2/\text{MM Btu}}$$

The NO_x mass emission rate based upon the maximum firing rate of the gas turbine alone is calculated as follows:

$$(0.00897 \text{ lb/MM Btu})(1872 \text{ MM Btu/hr}) = \mathbf{16.8 \text{ lb NO}_x/\text{hr}}$$

The NO_x mass emission rate when duct burner firing occurs is based upon the maximum combined firing rate of the gas turbine and HRSG and is calculated as follows:

$$(0.00897 \text{ lb/MM Btu})(2226.5 \text{ MM Btu/hr}) = \mathbf{20.0 \text{ lb NO}_x/\text{hr}}$$

CARBON MONOXIDE EMISSION FACTORS

Combustion Gas Turbine and Heat Recovery Steam Generator Combined

The combined CO emissions from the CTG and HRSG duct burner will be conditioned to a maximum controlled CO emission limit of 10 ppmv, dry @ 15% O₂ during all operating modes except gas turbine start-up and shutdown. The emission factor corresponding to this emission concentration is calculated as follows:

$$(6 \text{ ppmv})(20.95 - 0)/(20.95 - 15) = 21.13 \text{ ppmv, dry @ 0\% O}_2$$

$$(21.13/10^6)(\text{lbmol}/385.3 \text{ dscf})(28 \text{ lb CO}/\text{lbmol})(8535 \text{ dscf}/\text{MM Btu})$$

$$= \mathbf{0.013 \text{ lb CO}/\text{MM Btu}}$$

The CO mass emission rate based upon the maximum firing rate of the gas turbine alone is calculated as follows:

$$(0.013 \text{ lb}/\text{MM Btu})(2226.5 \text{ MM Btu}/\text{hr}) = \mathbf{29.2 \text{ lb CO}/\text{hr}}$$

The CO mass emission rate when duct burner firing occurs is based upon the maximum combined firing rate of the CTG and HRSG and is calculated as follows:

$$(0.022 \text{ lb}/\text{MM Btu})(2,124 \text{ MM Btu}/\text{hr}) = \mathbf{46.73 \text{ lb CO}/\text{hr}}$$

PRECURSOR ORGANIC COMPOUND (POC) EMISSION FACTORS

Combustion Gas Turbine

General Electric has predicted a maximum POC (non-methane, non-ethane hydrocarbon) emission rate of 4.77 lb/hour for full load operation of the gas turbine alone and 5.57 lb/hr for full load operation of the gas turbine with duct burner firing and steam injection power augmentation. These mass emission rates are derived from the BACT specification for POC of 2 ppmv, dry @ 15% O₂.

This converts to an emission factor as follows:

$$\text{POC} = (4.77 \text{ lb}/\text{hr})/(1872 \text{ MM Btu}/\text{hr}) = \mathbf{0.00255 \text{ lb}/\text{MM Btu}}$$

Converting to a concentration yields:

$$[(0.00255 \text{ lb}/\text{MM Btu})(10^6)(385.3 \text{ dscf}/\text{lbmol})]/[(16 \text{ lb CH}_4/\text{lb-mol})(8535 \text{ dscf}/\text{MM Btu})]$$

$$= \mathbf{7.19 \text{ ppmvd @ 0\% O}_2}$$

Converting to 15% O₂:

$$(7.19 \text{ ppmvd})(20.95 - 15)/(20.95) = \mathbf{2 \text{ ppmvd @ 15\% O}_2}$$

Combustion Gas Turbine and Heat Recovery Steam Generator Combined

General Electric, the turbine vendor, has predicted a maximum POC (non-methane, non-ethane hydrocarbon) emission rate of 5.57 lb/hr for full load operation of the gas turbine with duct burner firing and steam injection power augmentation.

This converts to an emission factor of:

$$(5.57 \text{ lb/hr})/(2226.5 \text{ MM Btu/hr}) = \mathbf{0.00250 \text{ lb/MM Btu}}$$

Converting to a concentration yields:

$$[(0.00250 \text{ lb/MM Btu})(10^6)(385.3 \text{ dscf/lbmol})]/[(16 \text{ lb CH}_4/\text{lb-mol})(8535 \text{ dscf/MM Btu})]$$
$$= 7.06 \text{ ppmvd @ 0\% O}_2$$

$$\text{Converting to 15\% O}_2: \quad (7.06 \text{ ppmvd})(20.95 - 15)/(20.95) = 2 \text{ ppmvd @ 15\% O}_2$$

PARTICULATE MATTER (PM₁₀) EMISSION FACTORS

Combustion Gas Turbine

General Electric has predicted a PM₁₀ emission rate of 11 lb/hr at maximum load for the gas turbine. The corresponding PM₁₀ emission factor is therefore:

$$(11 \text{ lb PM}_{10}/\text{hr})/(1872 \text{ MM Btu/hr}) = \mathbf{0.0059 \text{ lb PM}_{10}/\text{MM Btu}}$$

The following stack data will be used to calculate the grain loading at standard conditions for full load gas turbine operation without duct burner firing to determine compliance with BAAQMD Regulation 6-310.3.

PM ₁₀ mass emission rate:	11 lb/hr
flow rate:	1,044,947 acfm @ 12.54% O ₂ and 195°F
moisture content:	7.75 % by volume

Converting flow rate to standard conditions:

$$(1,044,947 \text{ acfm})(70 + 460^\circ\text{R}/195 + 460^\circ\text{R})(1 - 0.0775) = 780,007 \text{ dscfm}$$

Converting to grains/dscf:

$$(11 \text{ lb PM}_{10}/\text{hr})(1 \text{ hr}/60 \text{ min})(7000 \text{ gr/lb})/(780,007 \text{ dscfm}) = 0.0016 \text{ gr/dscf}$$

Converting to 6% O₂ basis:

$$(0.0016 \text{ gr/dscf})[(20.95 - 6)/(20.95 - 12.54)] = 0.0028 \text{ gr/dscf @ 6\% O}_2$$

Combustion Gas Turbine and HRSG Combined

The PM₁₀ emission factor is based upon the General Electric vendor prediction of 13 lb/hr at the maximum combined firing rate of 2226.5 MM Btu/hr during duct burner

firing and steam injection power augmentation. The corresponding PM₁₀ emission factor is therefore:

$$(13 \text{ lb PM}_{10}/\text{hr})/(2226.5 \text{ MM Btu/hr}) = \mathbf{0.00584 \text{ lb PM}_{10}/\text{MM Btu}}$$

It is assumed that this PM₁₀ emission factor includes secondary PM₁₀ formation of particulate sulfates.

The following stack data will be used to calculate the grain loading for simultaneous CTG and HRSG operation at standard conditions to determine compliance with BAAQMD Regulation 6-310.3.

PM ₁₀ mass emission rate:	13 lb/hr
typical flow rate:	1,008,429 acfm @ 9.54 % O ₂ and 184 °F
typical moisture content:	15.96% by volume

Converting flow rate to standard conditions:

$$(1,008,429 \text{ acfm})(70 + 460 \text{ }^{\circ}\text{R}/184 + 460 \text{ }^{\circ}\text{R})(1 - 0.1596) = 697,463 \text{ dscfm}$$

Converting to grains/dscf:

$$(13 \text{ lb PM}_{10}/\text{hr})(1 \text{ hr}/60 \text{ min})(7000 \text{ gr/lb})/(697,463 \text{ dscfm}) = 0.002 \text{ gr/dscf}$$

Converting to 6% O₂ basis:

$$(0.002 \text{ gr/dscf})[(20.95 - 6)/(20.95 - 15.96)] = 0.007 \text{ gr/dscf @ 6\% O}_2$$

SULFUR DIOXIDE EMISSION FACTORS

Combustion Gas Turbine & Heat Recovery Steam Generator

The SO₂ emission factor is based upon an expected maximum natural gas sulfur content of 1.0 grains per 100 scf and a higher heating value of 1030 Btu/scf as specified by PG&E.

The sulfur emission factor is calculated as follows:

$$(1 \text{ gr}/100\text{scf})(10^6 \text{ Btu}/\text{MM Btu})(2 \text{ lb SO}_2/\text{lb S})/[(7000 \text{ gr}/\text{lb})(1030 \text{ Btu}/\text{scf})(100 \text{ scf})]$$
$$= \mathbf{0.00277 \text{ lb SO}_2/\text{MM Btu}}$$

The corresponding mass SO₂ emission rate at the maximum combined firing rate of 226.5 MM Btu/hr is:

$$(0.00277 \text{ lb SO}_2/\text{MM Btu})(226.5 \text{ MM Btu}/\text{hr}) = 6.18 \text{ lb}/\text{hr}$$

The corresponding SO₂ mass emission rate at the maximum gas turbine firing rate of 1872 MM Btu/hr is:

$$(0.00277 \text{ lb SO}_2/\text{MM Btu})(1872 \text{ MM Btu}/\text{hr}) = 5.19 \text{ lb}/\text{hr}$$

This is converted to an emission concentration as follows:

$$(0.00277 \text{ lb SO}_2/\text{MM Btu})(385.3 \text{ dscf}/\text{lb-mol})(\text{lb-mol}/64.06 \text{ lb SO}_2)(10^6 \text{ Btu}/8535 \text{ dscf})$$
$$= 1.95 \text{ ppmvd SO}_2 \text{ @ } 0\% \text{ O}_2$$

which is equivalent to:

$$(1.95 \text{ ppmvd})(20.95 - 15)/20.95 = 0.55 \text{ ppmv SO}_2, \text{ dry @ } 15\% \text{ O}_2$$

Toxic Air Contaminants

The following toxic air contaminant emission factors were used to calculate worst-case emissions rates used for air pollutant dispersion models that estimate the resulting increased health risk to the maximally exposed population. To ensure that the risk is properly assessed, the emission factors are conservative and may overestimate actual emissions.

Table A-2
TAC Emission Factors^a for Gas Turbines and HRSG Duct Burners

Contaminant	Emission Factor (lb/MM scf)
Acetaldehyde ^c	6.86E-02
Acrolein	2.37E-03
Ammonia ^b	13.7
Benzene ^c	1.36E-02
1,3-Butadiene ^c	1.27E-04
Ethylbenzene	1.8E-02
Formaldehyde ^c	1.10E-01
Hexane	2.59E-01
Naphthalene	1.7E-03
PAHs ^c	1.0E-03
Propylene	1.052E-01
Propylene Oxide ^c	4.78E-02
Toluene	7.26E-02
Xylene	2.89E-02

^aCalifornia Air Toxics Emission Factors (CATEF) Database as compiled by California Air Resources Board under the Air Toxics Hotspot Program or Ventura County APCD (VCAPCD, 1995).

^bbased upon maximum allowable ammonia slip of 10 ppmv, dry @ 15% O₂ for A-11 and A-13 SCR Systems

^ccarcinogenic compound

Table A-3
TAC Emission Factors for 10-Cell Cooling Tower

Toxic Air Contaminant	Maximum Concentration in Cooling Tower Return Water (ug/L)	Emission Factor ^a Per Cell (g/sec)
Arsenic ^b	5.71	2.27E-08
Beryllium	15	5.96E-08
Cadmium ^b	0.03	1.19E-10
Trivalent chromium ^b	6.66	2.65E-08
Copper	8.82	3.51E-08
Lead ^b	1.25	4.97E-09
Manganese	54.33	2.16E-07
Mercury	0.03	1.19E-10
Nickel	8.28	3.29E-08
Selenium	0.9	3.58E-09
Zinc	6.3	2.50E-08

^abased upon maximum drift rate of 0.0005% and operation of cooling tower at maximum flow rate of 125,000 gallons per minute; for example:

$$\text{Cu} = (8.82 \text{ ug/L})(0.000005)(12,500 \text{ gal/min})(3.785 \text{ L/gal}) / [(60 \text{ sec/min})(1\text{E}06 \text{ ug/g})]$$

$$= 3.51\text{E-}07 \text{ g/sec}$$

^bcarcinogenic compound

AMMONIA EMISSION FACTOR

Combustion Gas Turbine & Heat Recovery Steam Generator

Each Gas Turbine/HRSG power train will exhaust through a common stack and be subject to a maximum ammonia exhaust concentration limit of 10 ppmvd @ 15% O₂.

$$(10 \text{ ppmvd})(20.95 - 0)/(20.95 - 15) = 35.2 \text{ ppmv NH}_3, \text{ dry @ 0\% O}_2$$

$$(35.2/10^6)(1 \text{ lbmol}/385.3 \text{ dscf})(17 \text{ lb NO}_2/\text{lbmol})(8535 \text{ dscf/MM Btu})$$

$$= \mathbf{0.0133 \text{ lb NH}_3/\text{MM Btu}}$$

The NH₃ mass emission rate based upon the maximum firing rate of the gas turbine alone is calculated as follows:

$$(0.0133 \text{ lb/MM Btu})(1872 \text{ MM Btu/hr}) = \mathbf{34.8 \text{ lb NO}_x/\text{hr}}$$

The NH₃ mass emission rate when duct burner firing occurs is based upon the maximum combined firing rate of the gas turbine and HRSG and is calculated as follows:

$$(0.0133 \text{ lb/MM Btu})(2226.5 \text{ MM Btu/hr}) = \mathbf{29.5 \text{ lb NO}_x/\text{hr}}$$